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DIRECTOR OF LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT PATTERSON AIR FORCE BASE OHIO

PRELIMINARY MID-FIELD FLOW ANGLE MEASUREMENTS IN THE AFFDL 15 INCH SLOTTED WALL TUNNEL

BY

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The feasibility of obtaining high resolution flow angle data in the mid-field region under transonic flow conditions has been demonstrated. Data gathered in this manner are suitable as input to wall correction schemes and can serve to check adequacy of new wall designs. It remains to confirm whether or not the measurements are indeed accurate enough such that systematic reduction of mid-field discrepancies will yield interference free conditions on the test article

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FOREWORD

This report was prepared by Dr. Thomas M. Weeks of the AFFDL Flight Mechanics Division. The work was performed in-house and was accomplished in support of the Office of Naval Research and Air Force Office of Scientific Research at the request of their contractor Advanced Technology Laboratories, Jericho, New York. This work also supports AFFDL/FX Project 147601 and was conducted during October 1972.

This Technical Memorandum has been reviewed and is approved.

Philip P Antonatos
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Director
Flight Mechanics Division

SYMBOLS

c	-	Airfoil chord
E	-	Anemometer bridge voltage
E_o	-	Zero flow bridge voltage
u	-	Local stream velocity
M	-	Mach number
X	-	Streamwise position from airfoil center
α	-	Airfoil angle of attack
θ	-	Local flow inclination relative to probe
ρ	-	Local density
ϕ	-	Probe yaw angle

INTRODUCTION

A problem area continuing to receive considerable attention in transonic testing is that of wall interference. As test requirements become more stringent, the need to eliminate the influence of the tunnel wall and/or develop suitable correction procedure becomes mandatory. Recent NASA Langley results[1,2], for example, indicate that near Mach number unity finned bodies of revolution with blockage ratios in excess of 0.0010 exhibited (a) premature creep in the drag curves (b) delay in drag divergence and (c) change in the shape of the drag curves. Tests were conducted in the Langley 8 and 16 Foot Transonic Wind Tunnel, each having a conventional homogeneous porous wall.

As a matter of current practice throughout the transonic testing community walls are characterized as essentially homogeneous. Homogeneous wall correction theory based on linearized aerodynamic concepts is applied for those effects not directly eliminated by the wall. Now one observes that drag coefficient duplication to within a single drag count is a published goal. The need to test highly loaded maneuvering configurations is a hard requirement. There is an urgent need to separate out those similar effects attributable to improper Reynolds number versus those resulting from wall influence. For these reasons, at least, current practice falls short. Boundary conditions are no longer symmetrical

or homogeneous. Nonlinear effects are prevalent and numerical methods must be employed to solve the actual flow field and/or provide guidance for improved wall design. One important feature of the numerical schemes is the ability to input actual boundary conditions where known. The problem here is to establish with what accuracy such boundary conditions must be measured. In the larger facilities, flow angles may be seconds of arc, well beyond current capability to resolve.

Recently a transonic (high subsonic) wall interference reduction concept has appeared which lies intermediate between the pure numerical scheme and current state-of-the-art practice as described. This involves measurement of flow properties in the so-called mid-field or intermediate field of the test article. For the present discussion we regard the mid-field as a region lying outside the embedded supersonic region and yet far enough removed from the wall to avoid local periodic wall effects. Under these conditions where such a mid-field region exists, at least approximately, it is possible in concept to provide for the local accurate measurement of flow properties. Departures of these measured properties from those obtained theoretically or experimentally in a larger tunnel or from flight test serve as input to a wall correction/modification program. Suitable local adjustments to wall porosity and backside pressure could then be made to minimize these departures. Having accomplished this the body near field should more closely resemble the free flight condition.

The question still remains, as to the precision required in such a mid-field measurement. As an example, preliminary calculations by Ferri[3] indicate that in the mid-field region of a slender two-dimensional profile flow direction measurements must be accurate to within $\pm$ 2 to 3 minutes of arc.

In this report are described a set of measurements in the mid-field region of a biconvex airfoil. The tests were conducted at the Air Force Flight Dynamics Laboratory. A new probe[4], designed and developed in-house was used as the prime instrument for flow direction and provided the needed accuracy.

PROBE DETAILS AND CALIBRATION

The probe (Figure 1) consists of a quartz rod 0.06 inch in diameter ground to a 20° included angle wedge. On both sides of the wedge close to, but not touching the apex is deposited a thin (1000Å) platinum film 0.04 inch long and 0.005 inch wide. Four (4) gold film leads are provided to complete the two (2) sensor circuits. As currently configured the quartz rod is 0.5 inch long and is supported by a 0.125 inch diameter stainless steel tube. The probe was constructed by Thermo Systems Inc. (TSI) under AFFDL specifications and is used in conjunction with a pair of TSI Model 1050 constant temperature anemometers and Model 1057 signal conditioners. Additional probe details may be found in Reference 4.

As in the case for all hot wire and hot film probes operated at constant temperature, each sensor is placed in one leg of a bridge circuit. The Zero Ohms Adjust control is adjusted to yield the same bridge voltage for both sides of the sensor under zero flow inclination conditions. Bridge voltage becomes a function of sensor heat transfer which in turn is related to the local mass flux, ρu. It is conventional practice to seek a formal relationship of the King's law type namely

$$E^2 - E_o^2 = A(\rho u)^n \tag{1}$$

where A and n are obtained experimentally. The exponent n is nominally of the order of 0.5.

A series of calibration runs were made both in the AFFDL TGF Transonic Facility and the AFIT Subsonic Wind Tunnel. Bridge voltage characteristics were established as functions both of mass flux ρu and flow direction θ. Typical mass flux calibration results for zero flow angle appear in Figure 2. A wide range of Mach numbers (0.3 to 1.2) is included. Unit Reynolds numbers ranged from 2 to 6×10^6 per foot. It is seen that for a given overheat ratio (ratio of sensor operating resistance to measured cold resistance) each probe displays in log-log format an essentially linear mass flux characteristic with $n \approx 0.4$. An overheat ratio of 1.5 was selected based on sensor resistance values furnished by TSI. In Figure 3 typical flow angle response (bridge voltage difference) is plotted for zero yaw angle. It is noted that for $\theta < \pm 3^\circ$ a single straight line of ΔE vs θ results for a given probe, overheat ratio and total pressure. These curves are essentially Mach number independent. The noise floor of the probe signal limits resolution capability to ± 2 minutes of arc. Next, yaw sensitivity was established and presented in Figure 4. For $\theta \leq 6^\circ$ the probe is insensitive to yaw angles less than $\pm 10^\circ$.

The extent of aerodynamic probe deflection was calculated to be within $\pm$ 0.2 minutes. During the calibration testing the bridge voltage was monitored statistically

using a Princeton Applied Research Co., Correlation Function Computer, Model 101 and Fourier Analyzer, Model 102. It was found that the bulk of the dynamic signal content appeared as a 1600 Hz pure sine wave, the calculated natural bending frequency of the probe. The rms signal level (< 1 mv) agreed with the deflection calculation. This suggests that probe vibration is the principal contributor to the remaining signal noise and the addition of lateral stiffening of the probe support may yield even better resolution capability.

BICONVEX AIRFOIL TESTS

Perhaps the simplest case to explore the mid-field concept as described is the two-dimensional biconvex airfoil. Under ONR contract Advanced Technology Laboratories has developed numerical programs which compute the entire biconvex airfoil flow field under free-flight conditions. For M=0.91 the embedded shock region extends laterally to 1.1 chord. At their request two (2) models were constructed having 5 and 2.5 inch chords respectively. Models were equipped with pressure taps and designed to span the 15 inch tunnel. Airfoil angles of attack could be set at 0, $\pm 2^\circ$ and $\pm 4^\circ$. Side wall slots were covered with tape. Top and bottom tapered

slots were set at a nominal 10% porosity. Diffuser flaps were set straight back and tunnel total pressure was set at 2000 psfa. Mach numbers of 0.91 and 0.95 were chosen yielding unit Reynolds numbers nominally of $3x10^6$.

The probe (number 5019) was mounted two (2) inches from and parallel to the top wall with apex parallel to the wing leading edge. This placed the probe at the outer extremity of the embedded supersonic region for M=0.91, c=5 inch but within the supersonic region for M=0.95. Probe axial position was variable between 0.33 chord lengths ahead and 0.85 chord lengths behind the 5 inch airfoil. Typical traverse times were ten (10) minutes each way. Bridge voltages were displayed on a pair of digital voltmeters and hand recorded. Figure 5a, 5b present the results. In all cases data points were obtained while sweeping the probe in both directions. In some cases a complete sweep was accomplished on consecutive days. A particle impact destroyed this, the last available probe after twenty (20) hours of exposure.

COMPARISON WITH FREE FLIGHT THEORY

Preliminary theoretical results have been received from ATL corresponding to the $\alpha = 0^{\circ}$ case for M=0.91 and 0.95. The calculations are carried out using a numerical scheme described in Reference 5. In both cases (Fig 6) the

overall agreement may be considered quite good. Moreover, local departures between experiment and free flight theory may be regarded as due to the presence of the wall and may therefore be input directly into wall correction schemes. Theoretical work is in progress along these lines and additional AFFDL testing is scheduled.

CONCLUDING REMARKS

The feasibility of obtaining high resolution flow angle data in the mid-field region under transonic flow conditions has been demonstrated. Data gathered in this manner are suitable as input to wall correction schemes and can serve to check adequacy of new wall designs. It remains to confirm whether or not the measurements are indeed accurate enough such that systematic reduction of mid-field discrepancies will yield interference free conditions on the test article.

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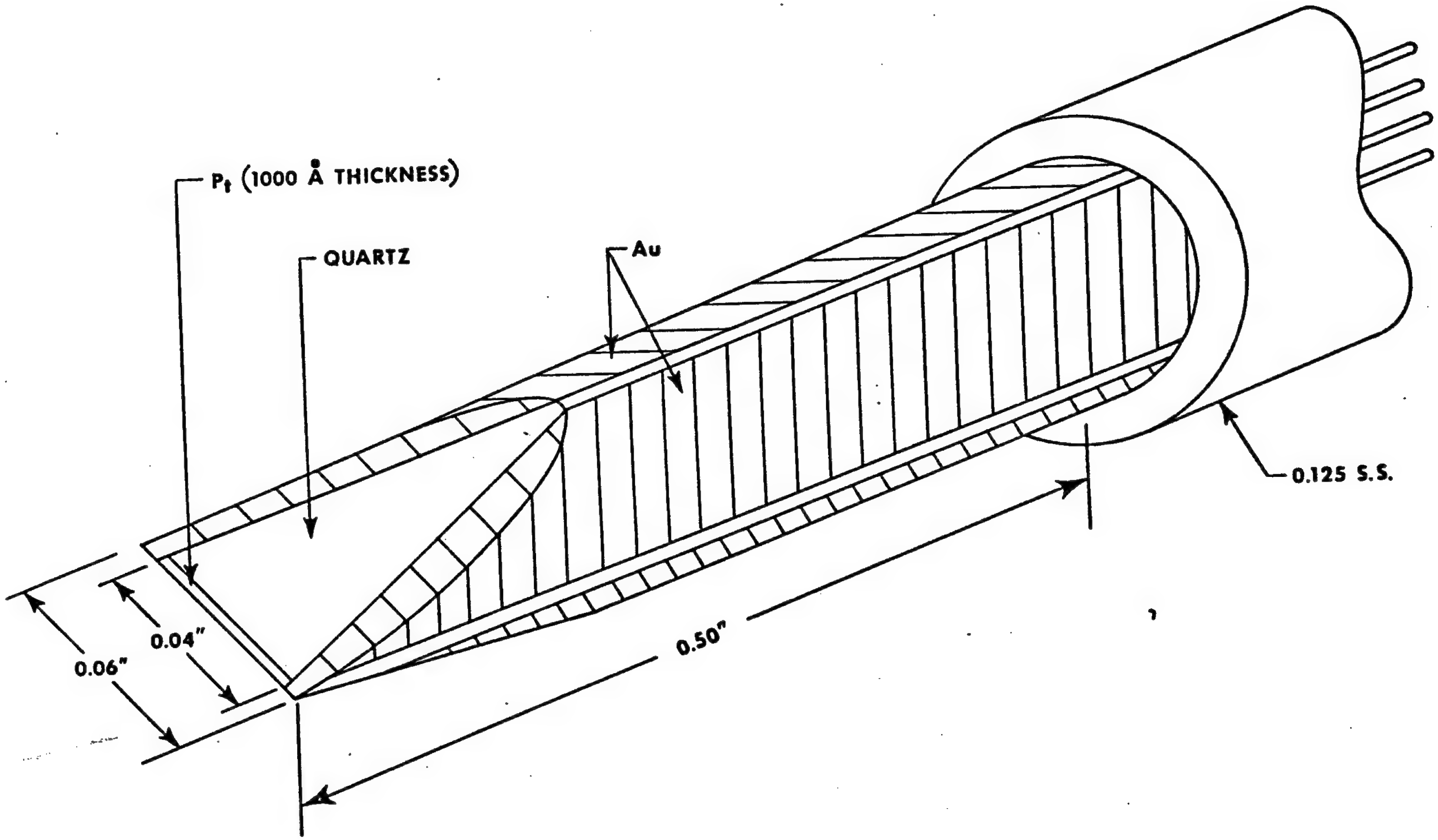

FIGURE 1. 20° HOT FILM SPLIT WEDGE PROBE DETAIL

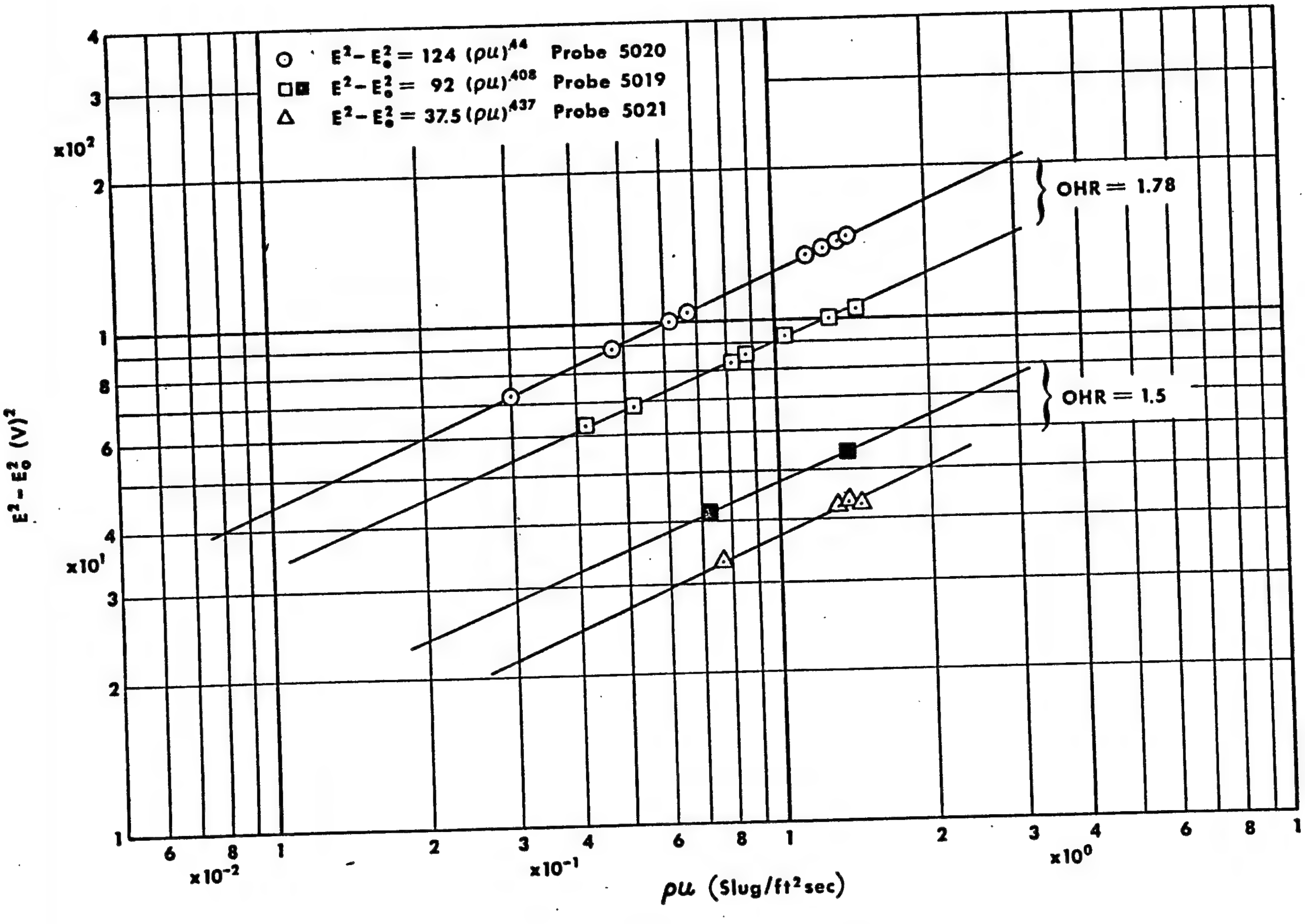

FIGURE 2. MASS FLUX CALIBRATION

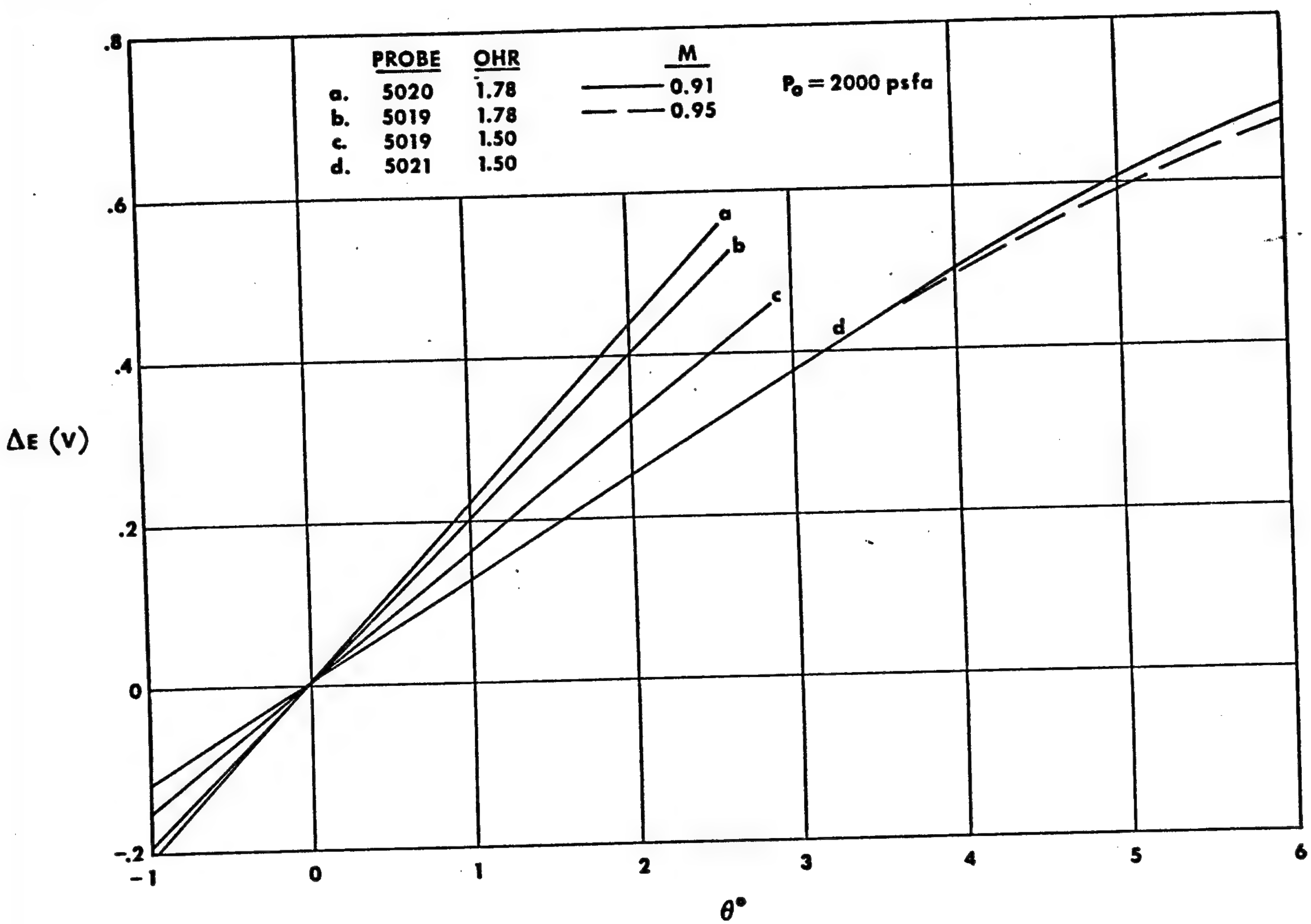

FIGURE 3. FLOW ANGLE CALIBRATION

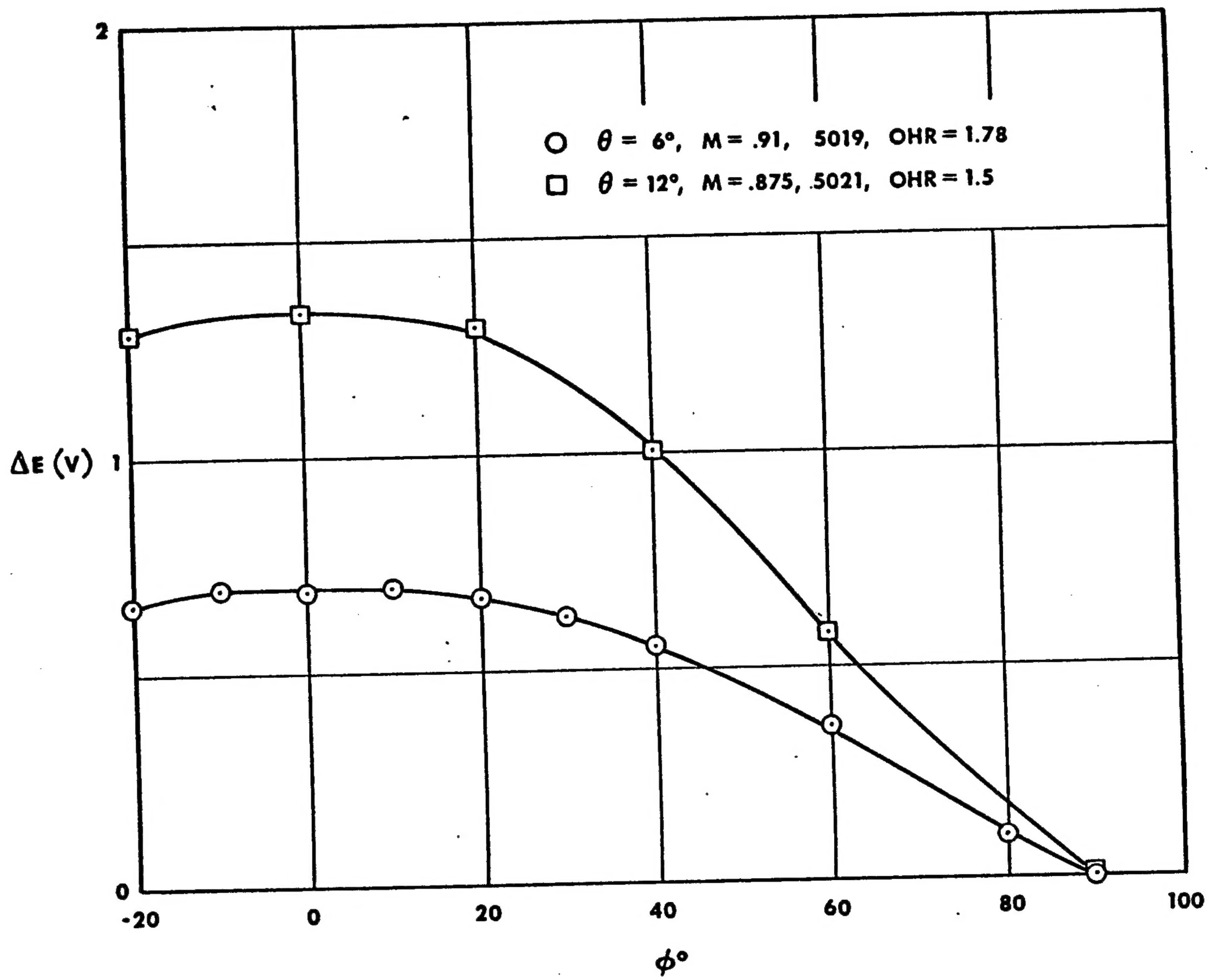

FIGURE 4. YAW SENSITIVITY

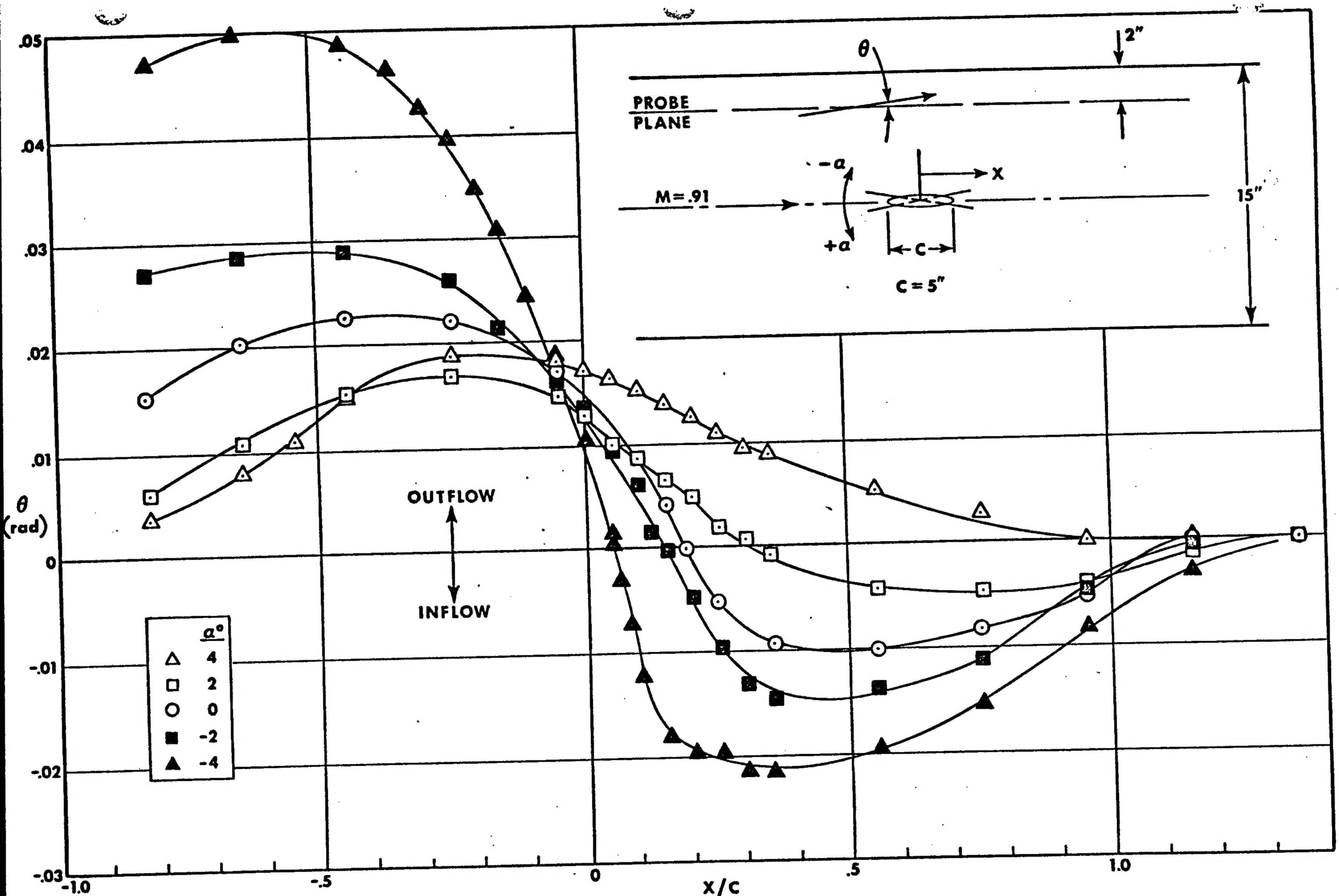

FIGURE 5a. BICONVEX AIRFOIL FLOW ANGLE SURVEY, M = .91

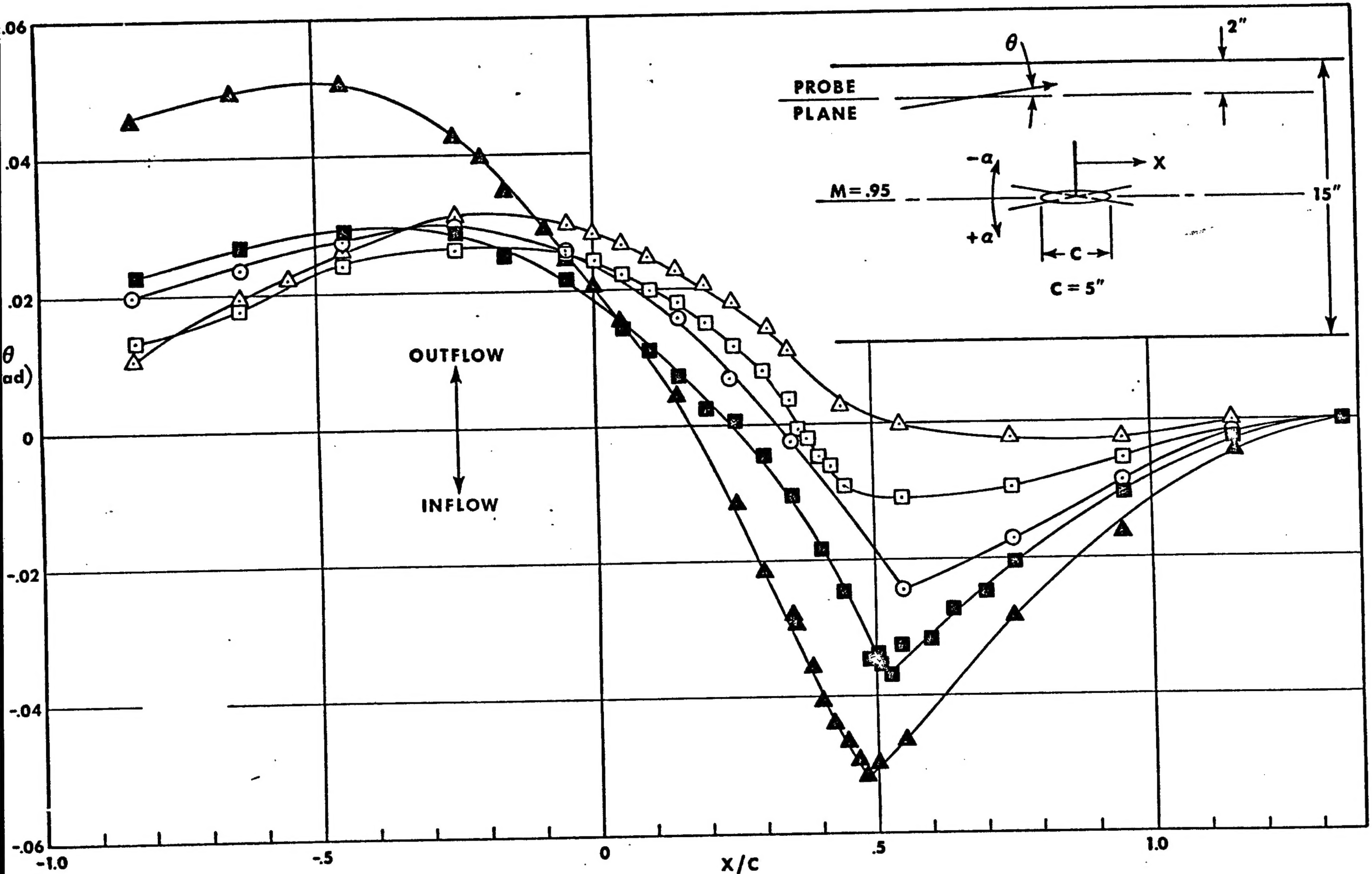

FIGURE 5b. BICONVEX AIRFOIL FLOW ANGLE SURVEY, M = .95

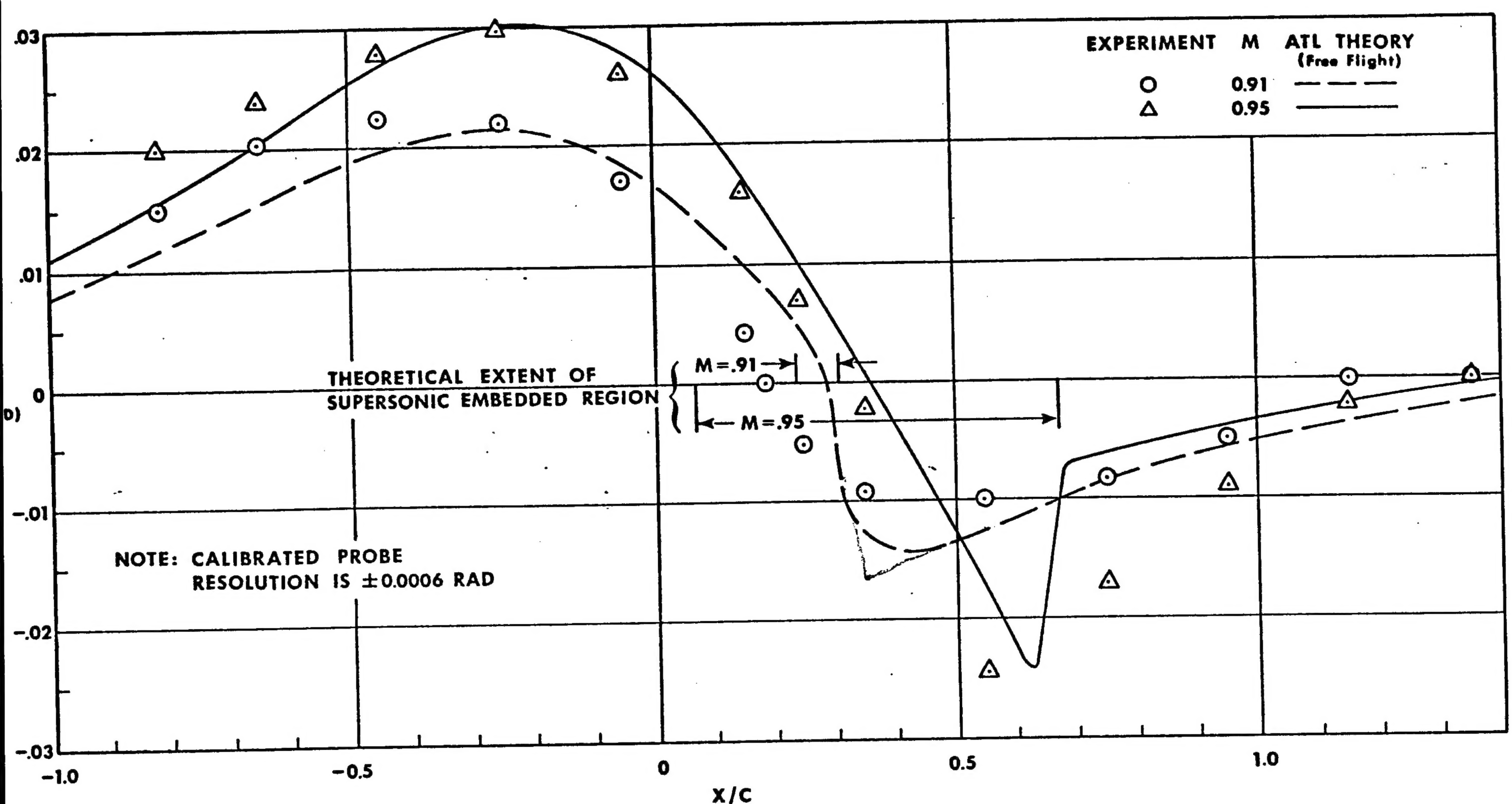

FIGURE 6. FLOW ANGLE, EXPERIMENT AND THEORY, $\alpha = 0°$